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OPTIMIZATION OF SPECIFIC FUEL CONSUMPTION AND EMISSIONS FOR DIESEL ENGINE USING TAGUCHI EXPERIMENTS

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ABSTRACT

It is known that Taguchi method helps to reduce the number of variables in a process or Experimental work through robust design of experiments. The main aim is to minimize the specific fuel consumption (SFC) and emissions. The Experimental work was carried out on four stroke C I engine using Esterified Neem oil methyl ester (NOME) and their blends. The performance parameters and emissions of direct Injection, diesel (DI) engine were tested for input parameters viz. load, Injection pressure and blend percentage. The dependent parameter such as Brake Specific fuel consumption (BSFC) and Emissions levels like Hydro carbons (HC), Carbon monoxide (CO), Carbon dioxide (CO_2) and Nitrogen oxides (NOx) were determined using AVL digi-gas analyzer. The optimum input parameters were determined using the design of experiments suggested by Taguchi to minimize the time, cost, to achieve high performance and low emissions. An ANOVA \analysis was carried out to optimize the input parameters contributing to the percentage output. The results of the Taguchi experiment proved that optimum BSFC could be obtained for 180 bar injection pressure for B75 blend with 40% load. The results also revealed that HC and NO_X emission are much lower for 220 bar injection pressure, for B75 with 40% load. Similarly, the CO is less at 180 bar, for B25 at 40% load. The reduction in CO_2 emission was observed at 200bar, for B75 at 60% load.

Keywords: Neem Oil Methyl Ester, Taguchi experiment, Diesel engine, ANOVA.

1. Introduction

The government is made policies usage to use biodiesel in transport and various sector in a recent year, because to minimize the pollution and also to reduce the import of crude oil by paying more foreign exchange. to promote use of Biofuels in the country, the NPB envisages an indicative target of 20% blending of ethanol in petrol by 2030 and 5% blending of biodiesel in diesel by 2030. This study confirms that, at what extent biodiesel usage is viable in running the diesel engine. But running engine with different biofuels and its blends for operational conditions is difficult and a lot of experimentation is required. To minimize experimental work up to maximum extent, we have used Taguchi design of experiments. In this study an ANOVA was applied to estimate the percentage control parameters contribution to lower the specific fuel consumption and emissions. However we cannot conclude the results obtained by Taguchi experiments are final, there should be some validation done on the results. Hence for validation purposes we have conducted the confirmatory experiment for the optimum parameters obtained by Taguchi method. The experimental results corelates well with the Taguchi values. A brief discussion of some important research findings in the field of biofuels with Taguchi approach has presented below.

Agarwal and Rajamanoharan [1] conducted experiment on single cylinder four stroke diesel engine. The study concluded that, specific fuel consumption for karanj oil blends more than diesel. The authors also noticed low heat release rate due to lower volatility and high viscosity of karanj oil and its blends. Modi, et al. [2] studied for palm seed oil blends with diesel engine by considering the parameters i.e. load, compression ratio and injection pressure were as an input variable. The Taguchi method was applied for optimization. The results of Taguchi experiments proved that compression ratio, injection pressure of 180 bar and load of 10kg were an optimum parameter to reach highest brake thermal efficiency. Sahin et al. [3] carried out an experiment, to exhibit the effects of gasoline fumigation (GF) on the performance and exhaust emissions of a turbocharged indirect injection diesel engine. The results reveal that effective power was generally reduced and effective efficiency was raised up. Brake Specific Fuel Consumption (BSFC) was decreased and its decrement ratios are roughly at the levels of 5%. NOx concentration in exhaust gas was decreased and also Smoke index was fall down 12%–8%. Nimesh et al. [4] Taguchi method was applied to determine an optimum injection pressure which lowers the emissions. The injection pressure was increased from 100 to 250 bar with an increment of 50 bar. The performance parameters such as power, torque and specific fuel consumption were recorded. The maximum performance was achieved at 150 bar pressure and 2500 rpm. The CO_2 emissions was higher as the injection pressure increases. The lower injection pressure yields minimum NO_X and smoke emissions. Prasada et al. [5] carried out experiments with Mahua methyl ester as a fuel for indirect injection diesel engine. The performance and emission parameters were recorded. Taguchi technique and Grey Relational analysis were used to determine an optimal combination of the load and fuel by converting the multi-response problem into the single-response problem. Load of 20 kg and 3% of mahua methyl ester was found to be an optimum condition. Avinash et al. [6] studied on diesel engine by varying injection pressure, nozzle holes, and compression ratio Pongamia methyl ester blends was used to test the engine performance. Taguchi method was applied for Brake thermal efficiency optimization. Maximum performance was observed for injection pressure of 200 bar, 3 nozzle holes and compression ratio of 18. Shivaram et al. [7] carried out study how the input parameters influences on performance and the emissions of a single-cylinder diesel engine. Taguchi method was applied for five parameters, viz, power, static injection pressure, injection timing, fuel fraction, and compression ratio. The parameters were varied at four levels to study the responses on SFC and break power. Nataraj et al. [8] Taguchi method were applied in their experiment to lower the emissions of diesel engine. The effect of nozzle spray holes, piston to head clearance, nozzle position, injection control pressure, and swirl were optimized by these techniques. The result, as found by the Taguchi method, shows lower HC and CO emissions compared to base-line reading. kulunk et al. [9] used Taguchi Method in their experiment to optimize the parameters for better engine performance and low pollutant. The analysis of variance (ANOVA) were employed to find the optimum levels and to analyze the effect of operation conditions on performance and emission values. The parameters and their levels are engine speeds at 1200, 1600, 2000 and 2400 rpm, steam ratios of 0, 10, 20 and 30% and EGR ratios of 0, 10, 20 and 30%. Confirmation tests with the optimal levels of engine parameters were carried out in order to illustrate the effectiveness of the Taguchi optimization method. Siju [10] has studied on direct ignition CI engine with Karanja Biodiesel with combined effect of EGR and Injection Pressure. The number of experiments was reduced byTaguchi method of DOE. Optimum parameters from Taguchi method were validated by experiments and compared the results. The optimum sets were found for BSFC and BTE at 10% Blend, 0% EGR, 180 bar Injection Pressure and 12 kg Load.

2. Experiment Details and Methodology

The experimental work were conducted on a single cylinder, water cooled diesel engine coupled with an electrical loading. Initially, the engine was started by manual cranking with diesel fuel and run at idling RPM for about five minutes without load, to warm up the engine and also to stabilize all the parameters. By altering governor mechanism, required engine speed was achieved. The time taken to consume 10 ml of biodiesel blends at different loading was recorded. The parameters such as voltage, current and temperature were measured. The constant engine speed of 1500 RPM was maintained through out the experiment. The speed of engine being ensured by digital contact type tachometer. The cooling water and exhaust gas temperature was measured using thermocouples and also air box

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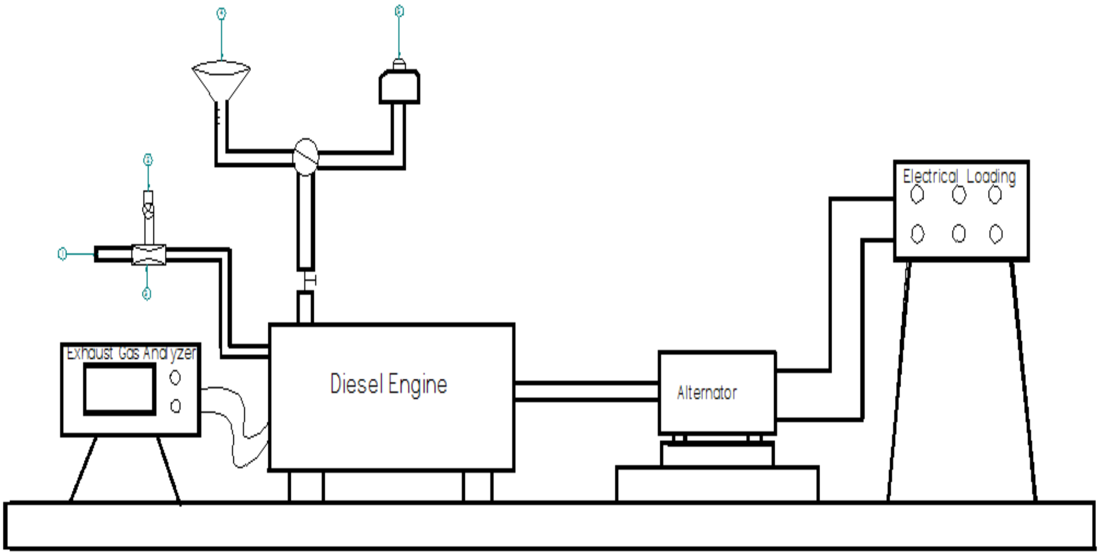
method were adopted to measure air consumption rate. The above procedures were replicated for biodiesel blends of 25%, 50%, 75%, and 100% with esterified Neem oil (NOME). The injection timing was advanced from 26° BTDC to 24.5° BTDC by removing shim of 0.3 mm thickness and then to 23° BTDC. The nozzle opening pressure was varied by changing nozzle spring tension. The nozzle opening pressure was increased by 180 bar to 220 bar with an increment of 20 bar. AVL Digas 444 analyzer was used for emission measurement. The technical specifications are given in Table 1. The schematic diagram of experiment is shown in fig. 1.



1-Air in 2-Biogas in 3-Venturi 4-Biodiesel in 5-Diesel tank

Fig.1 Schematic diagram of experimental setup

Table 1: Technical Specification of AVL Digas Analyzer

Sl.No	Measured parameter	Specification
1	Oxygen	0-22% vol
2	Carbon dioxide	0-10% vol
3	Carbon monoxide	0-10% vol
4	Hydro carbon	0-20000 ppm
5	Nitrogen oxide	0-5000 ppm
6	Engine speed	400- 6000 rpm
7	Oil temperature	- 30 to 125o C
8	Lambda	0 to 9.999

The objective of the work is to determine the effect of injection angle advance and injection pressure on emissions and fuel economy and also to identify the optimized range of input parameters for low emissions and better fuel economy. Taguchi technique was used to identify the key factors that make the greatest contributions to the variation in response parameters of interest.

3. Result and discussions

The present study uses three factors at three levels and each one has two degrees of freedom. Also, the interactions between the parameters are neglected as the parameters are independent. Hence, an L9 orthogonal array was used to tabulate the results of calculated SN ratio as well as the sum of squares also given in Table 2.

Table 2: SN ratio and sum of squares for SFC

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Experiments	Injection pressure in bar	Blend ratio	Load in %	SFC	SN Ratio	SOS
1	10	25%	40	0.485	15.827	0.079
2	180	50%	60	0.456	15.122	0.065
3	180	75%	80	0.435	15.073	0.441
4	200	25%	80	0.383	17.878	3.133
5	200	50%	40	0.479	15.935	0.030
6	200	75%	60	0.428	16.913	0.648
7	220	25%	60	0.415	17.181	1.151
8	220	50%	80	0.427	16.933	0.681
9	220	75%	40	0.591	14.110	3.991
Average					16.435	10.509

The Taguchi orthogonal Array L9 experiments were also used to determine emissions such as Hydrocarbons (HC), carbon monoxide (CO), carbon dioxide (CO_2), and oxides of nitrogen (NO_X). The SN ratio was given in Table 3.

Table 3: S/N ratio for Emissions

Experiment	HC	CO	CO_2	NO_x
1	17.692	-33.979	-0.756	40.000
2	17.306	-35.563	0.880	41.339
3	19.401	-35.563	3.618	43.991
4	18.416	-40.000	2.819	42.499
5	14.540	-35.563	-2.270	38.416
6	12.736	-40.000	-0.385	39.244
7	13.380	-40.000	-0.205	39.493
8	15.067	-43.522	2.390	42.279
9	10.458	-40.000	-5.088	36.478
Total mean S/N ratio	15.444	-38.243	0.111	40.416

Calculated, response graphs were plotted. These are depicted in Fig. 2 to Fig. 6

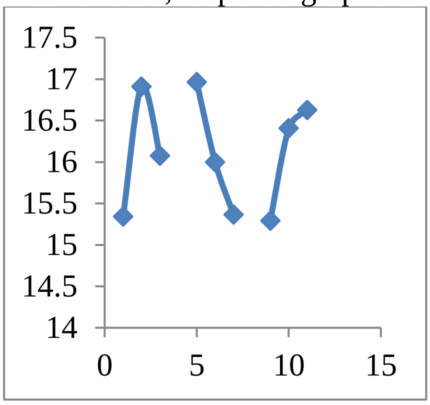

Fig. 2: Response parameters for SFC

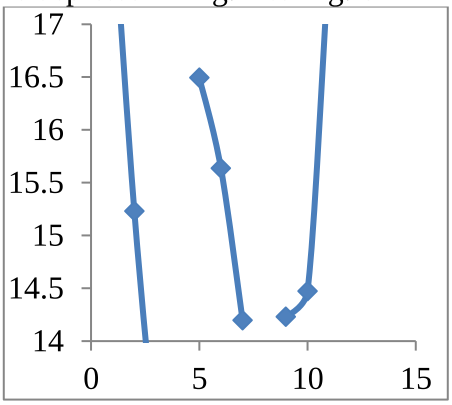

Fig. 3: Response parameters for HC

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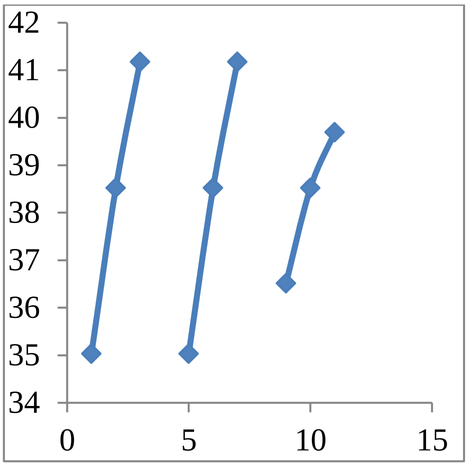

Fig. 4: Response curve for CO

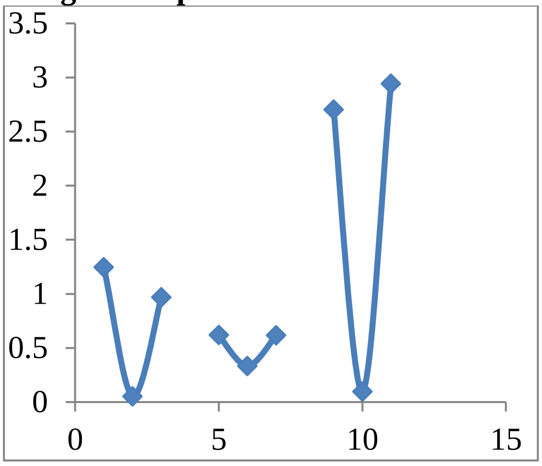

Fig. 5: Response curve for CO_2

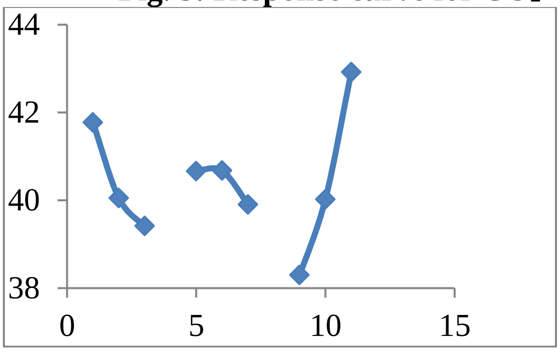

Fig. 6: Response curve for NO_X

From the response graph (Fig.2-6), using the "smaller the better" criterion for lowest emission values of SFC and HC, CO, CO_2 and NO_X , the optimum value of input parameters were identified, and these are shown in Table 4 and Table 5.

Table 5: Optimum values of input parameters for better SFC

Optimum response parameters		
Injection pressure in bar.	**Blend ratio**	**Load in %**
180	75	40

Table 6: Optimum values of input parameters for lower emission

HC	CO	CO_2	NO_x

A3	B3	C1	A1	B1	C1	A2	B2	C2	A3	B3	C1
220bar	75%	40%	180bar	25%	40%	200bar	50%	60%	220bar	75%	40%

Analysis of variance (ANOVA) was also carried out to determine the relative contribution of the input three parameters (injection pressure, blend % and engine load) to SFC and four emission variables (HC, CO, CO_2 and NO_X). These results are shown from Table 6 to 11.

Table 7: ANOVA results for SFC

Source of Variation	DOF	Average SOS	Variance	True Variance	F-RATIO	Contribution in %
Injection pressure (A)	02	3.811681	1.905341	3.810	0.30017	30.017
Percentage of blend (B)	02	4.269882	2.31441	4.262	0.36461	36.461
Load in percent (C)	02	4.25568	2.12784	4.255	0.33522	33.522
			Sum = 12.695			

Table 8: Analysis of Variance for **HC**

Source of Variation	DOF	Average SOS	Variance	True Variance	F-RATIO	Contribution in %
Injection pressure (A)	02	8.081	4.040	8.081	0.361	36.127
Percentage of blend (B)	02	6.058	3.029	6.05	0.271	27.084
Load in percent (C)	02	8.229	4.114	8.229	0.368	36.789
			Sum = 22.3671			

Table 9: Analysis of Variance CO

Source of Variation	DOF	Average SOS	Variance	True Variance	F-RATIO	Contribution in %
Injection pressure (A)	02	12.712	6.356	28.511	0.446	44.600
Percentage of blend (B)	02	4.452	2.226	4.452	0.156	15.616
Load in percent (C)	02	12.712	5.673	12.712	0.398	39.800
			Sum = 28.511			

Table 10: Analysis of Variance for CO_2)

Source of Variation	DOF	Average SOS	Variance	True Variance	F-RATIO	Contribution in %
Injection pressure (A)	02	4.546	2.273	4.546	0.292	29.246

Percentage of blend (B)	02	2.727	1.363	8.271	0.175	17.543
Load in percent (C)	02	8.271	4.136	2.727	0.532	53.211
			Sum = 15.544			

Table 11: Analysis of Variance for NO_X

Source of Variation	DOF	Average SOS	Variance	True Variance	F-RATIO	Contribution in %
Injection pressure (A)	02	4.604	2.302	4.604	0.347	14.010
Percentage of blend (B)	02	1.783	0.894	1.788	0.135	34.307
Load in percent (C)	02	6.866	3.433	6.866	0.518	51.650
			Sum = 13.258			

Pareto analysis for NOME and its blends are shown form Fig. 7 to 11. It is seen from Fig.7 that the blend ratio of NOME has the maximum influence on SFC (36.4%), followed by engine load (33.5%). Injection pressure also has considerable influence (30%).

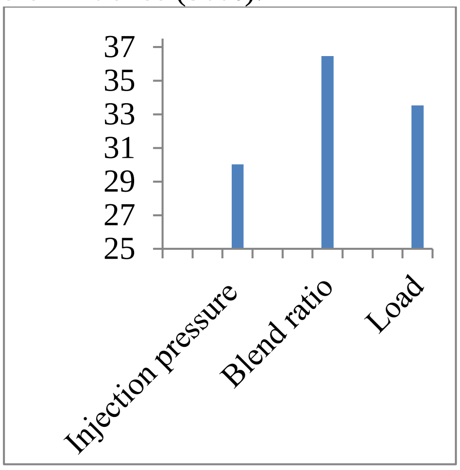

Fig. 7: Contribution plot for SFC

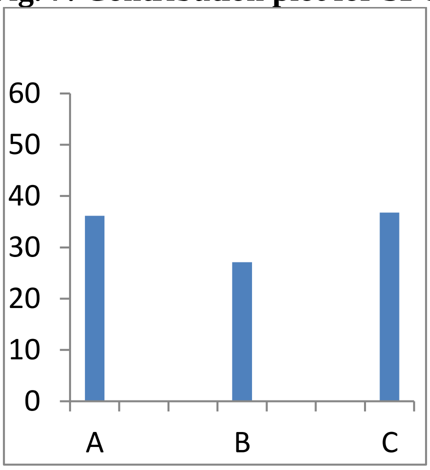

Fig. 8: Contribution plot for HC

X-parameters A-Injection pressure, B-Blend ratio, C-Load Y-percentage of contribution

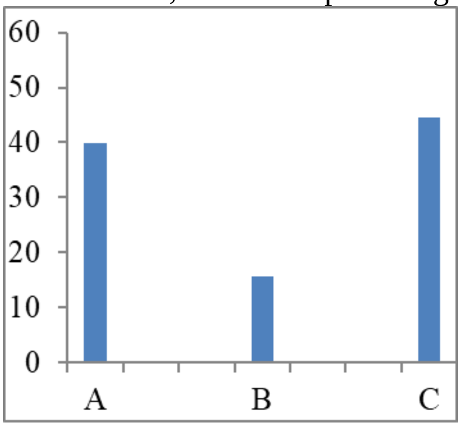

Fig. 9: Contribution plot for CO

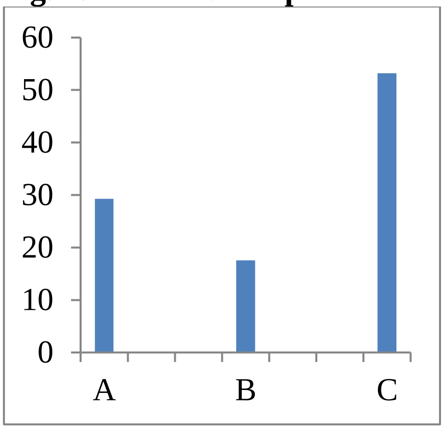

Fig. 10: Contribution plot for CO_2

The Fig.8 presents the relative contribution of input parameters on HC emission. From the Fig. it shows that injection pressure is influencing more to lower HC emission fallowed by load. As the injection pressure is higher, that helps to break fuel droplet into fine particles and helps to prepare proper air-fuel mixture. Thus the mixture under goes complete combustion and also at higher load the temperature of the chamber increases, this leads to pre-heating of mixture.

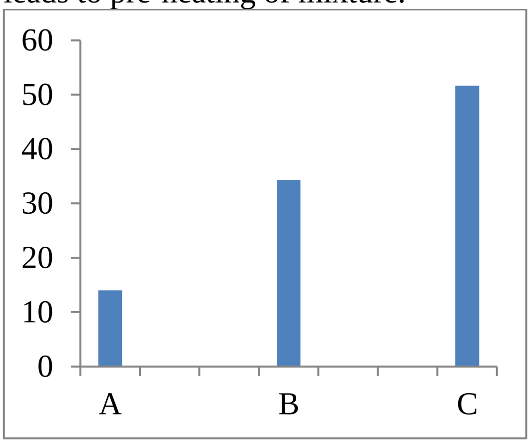

Fig. 11: Contribution plot for NO_X

Higher combustion temperature at higher engine load contributed to the decrease in **CO** emission with the addition of biodiesel. It was possible that the oxygen contained in the fuel facilitated complete combustion in the cylinder and reduced **CO** emission was observed from Fig.9. From the Fig. 10 it clears that load is influencing more to reduce **CO_2** emission fallowed injection pressure. This is because of higher operating temperature, proper mixing of fuel particles with air and higher oxygen availability by biodiesel limits **CO_2** emission.

Form the Fig. 11 observed that injection pressure fallowed by blend ratio are influencing to lower NO_x emission significantly. Decreased fuel injection pressure reduces oxides of nitrogen emissions this is because for given fuel injection pressure, the biodiesel content in the fuel blend decreases.

4. Conclusion

In this study, an attempt was made to optimize the FIVE response parameters by varying three inputs simultaneously. The Taguchi method was adopted to limit the number of experiments and ANOVA was carried out to determine influence of input parameters on response parameters. Based on the results of this study, the following conclusions were drawn in terms of SFC and exhaust emission characteristics.

HC			**CO**			**CO_2**			**NO_x**		
A3	B3	C1	A1	B1	C1	A2	B2	C2	A3	B3	C1
220bar	75%	40%	180bar	25%	40%	200bar	50%	60%	220bar	75%	40%

1. The optimum SFC could be obtained for 180 bar injection pressure, B75 blend, and 40% load
2. As the blend ratio increased, it was observed that higher SFC than diesel.
3. From the Taguchi analysis, the following optimum control parameters for HC, CO, CO_2 and NO_X were found.
4. Load was the major significant factor which influences the HC emission fallowed by injection pressure.
5. Lower CO emission was observed at injection pressure of 180 bar, 25 % blend and 40 % load.
6. Lower CO_2 emission was shown at injection pressure of 200 bar, 50 % blend and 60 % load.
7. injection pressure of 220 bar, 75 % blend and 40 % load will lowers the NO_X emissions.

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